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Operators' exposure to noise and vibration in the grass cut tasks: comparison between private and public yards

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Abstract: During the green maintenance, the grass cut tasks require the operators to use machines (especially lawn tractors, mowers, blowers and brush cutters) which transmit them high levels of noise and vibration. The requests of the Directive 2003/10/EC for the operators' noise exposure are difficult to be applied in seasonal variable activities, as grass cut tasks are. The same problem exists in case of the workers' exposure to vibration sources. Aim of this work was to compare the noise and vibration operators exposure of a public yard with a private one in the grass cut tasks. Data were collected using the requested standards considering all the noisy and vibrating sources of the operators. Moreover, the different work organisation in the two yards was considered. The results showed that there are not significant differences among the two yards types for the noise risk: the limit value was exceeded for almost all the workers: in this case operators must be protected by the hearing protector devices. For the hand-arm vibration risk, the operators of the private yard are conversely slightly more exposed: in this case major problems are present, because it is more difficult to protect the operators.

Keywords: noise, vibration, grass cut, exposure times

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1 Introduction

Since many years Whole-Body Vibration (WBV), Hand Arm Vibration (HAV) and noise exposures have been recognized as significant sources of discomfort for forestry and agricultural operators (Chisholm et al., 1992; Bovenzi, 1994; Cerruto et al., 2003; Sorainen et al., 1998; Taoda et al., 1998; Riccioni et al., 2015).

Agricultural and forestry operators really use various sources of noise and vibration, e.g. agricultural tractors, self-propelled agricultural machines, chain saws, brush cutters, blowers, grass trimmers and so on. Some Authors (Iki et al., 1985; Sorainen et al., 2005) found a correspondence between vibration and hearing loss in forestry workers.

Each machine is work and environment depending and may be used for different periods of time. Moreover, the age, the characteristics and the maintenance level of the machines also influence the sound pressure and the vibration levels (Franklin et al., 2006). In agriculture the trend is to not frequently change machines and it is quite common to find old machineries generating high level of noise and vibration (Depczynski et al., 2005; Sümera et al., 2006).

In these situations, where it is impossible to operate on the emission values, the exposure times play a key role (Solecki, 2000).

Unfortunately, while the sound pressure, the vibration levels and the exposure times are easy to obtain in repetitive tasks (especially in the factory, where the job description is well defined a priori), in agricultural and forestry works the situation is quite different. In this case machines and tools (with high level of noise and vibration emissions) may be used more than 8 hours/day for long periods of time and may not be used in other seasons (Sorainen et al., 1998).

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Regardless the period of the machine use, also if the operator is exposed for a short period of time to acoustic and vibration emissions, European Directives 2003/10/EC and 2002/44/EC oblige to do the risk evaluation and to declare both the daily exposure values $L_{EX,8h}$.(noise) and *A(8)* (vibration).

In both the cases, the duration of the exposure is very important: unfortunately it is often an underestimated or imprecisely defined parameter which may greatly influence the daily exposure values (Griffin, 1994; Gerhardsson et al., 2005; McCallig, 2010).

Aim of this work was both to compare the declared exposure times in different situations and to verify how it could influence the exposure levels in two different (public and private) yards for the green maintenance, considering the grass cut task.

The gardening and the green maintenance of public and private areas are activities that increased in the last years (Piccarolo, 2006; Knibbs, 2014), involving an increasing number of public and private employees that use noisy and vibrating machines. The consequence has been a significant increment of environmental noise and occupational noise and vibration exposure (Tint et al., 2012).

Moreover, in all the different urban green typologies the turf is the main component: in an urban park, for example, the turf represents the 40%-50% of the vegetal component. As a consequence, the 80% of the total work is represented by the grass cut and this operation obliges the public operators to use mechanical tools for many hours (Piccarolo, 2006). In the private yards, instead, operators must cut the grass in function of the customer request: while the public grass cutters have a fixed job distribution, as required by the local authority, the private ones share different activities among their operators.

2 Materials and methods

2.1 The European Directive for noise exposure and the daily exposure value ($L_{EX,8h}$)

In Europe, the operator's noise exposure at the workplace is regulated by the European Directive 2003/10/EC. The noise is a form of energy and the negative effects on the human ear does not only depend from the level, but also from the duration: for example a one hour exposure to a noise of 90 dB(A) is more dangerous than a 4-hour exposure to a noise of 82 dB(A). For this reason it is important to calculate the daily exposure value $L_{EX,8h}$ (Equation (1)), which represents the ear deficit risk of a person during his eight working-day hours (this period of time is assumed as default by the Directive).

$$L_{EX,8h} = L_{Aeq} + 10log_{10}\frac{T_e}{8} \quad (1)$$

where:

L_{Aeq}: acoustic pressure level measured at the operator's ear, dB(A)

Te: daily exposure time to the noisy source, hour

When the operator uses different noisy machines, it is necessary to use another formula (Equation (2)), which considers the acoustic pressure levels and the exposure times for each equipment.

$$L_{EX,8h} = 10\ log_{10}\left(\sum_{i=1}^{M}\frac{T_i}{8}10^{0,1\times L_{Aeqi}}\right) \quad (2)$$

where:

L_{Aeqi}: acoustic pressure level measured at the operator's ear using the machine *i*, dB(A)

T_i: operator's exposure time when he uses the machine *i*, hour

M: number of the noisy machines used daily by the operator.

Lawton (2001) analysed that after 30 years of work with a $L_{EX,8h}$ of 90 dB(A), 13% of subjects could risk an hearing deficit higher than 25 dB(A), whereas for a 75 dB(A) daily exposure the risk did not exist. The percentage increases to 48% for daily exposures of 100 dB(A) (ISO 1999:2013). Lawton (2001) indicated that broadband noise at 75 dB(A) did not produce measurable dullness of hearing at 4 kHz, even after 8-hour exposures, whereas a noise of 80 dB(A) produced a temporary threshold shift which recovered in some minutes after the noise ceased.

In any case the 2003/10/EC Directive sets exposure limit values and exposure action values in respect of the daily noise exposure levels $L_{EX,8h}$ and of peak sound pressure P_{peak} (Table 1).

Table 1 Actions to be considered in function of the different exposure values (2003/10/EC Directive)

$L_{EX,8h}$, dB(A)	P_{peak}, dB(C)	Action
$80 \leq L_{EX,8h} < 85$	135	Lower exposure action values: information and training are provided. The employer must provide HPD to the workers. Audiometric tests are available.
$85 \leq L_{EX,8h} \leq 87$	137	Upper exposure action value: HPD must be used and the workers may require a medical assistance
$L_{EX,8h} > 87$	140	Exposure limit values: immediate action are to be taken to reduce the exposure below the exposure limit values

HPD: hearing protector device (EN ISO 4869-2:1995/AC:2007)

If the lowest action value is exceeded, the employer must declare the exposure level, type and duration, including the peak exposures, because exposure to peak noise exceeding 135 dB(C) can cause immediate damage to the worker.

In situations where remediation measures are applicable, it is mandatory action on the source.

Where it is possible, the noise mapping allows highlighting the areas where there are the higher noise levels. It is then conceivable, for example, separate technical noisy activities from not noisy ones, reduce noise at the source by replacing loud work equipment with another less noisy, reduce emissions at source by adjusting parameters or operation modes, adopt anti-vibration systems to reduce noise-borne, reduce noise by soundproofing or silencers.

Organizational changes as the workstations displacement, a proper maintenance, a staff turnover, an access limit to the noisy areas for non-specialists and a proper training to the employees are other good systems to limit the operators' noise exposure. If it is not possible to reduce the noise at the source, the only way to reduce the risk is to diminish the ear sound pressure with the hearing protector devices (HPD) and to establish working duties to reduce the daily exposure time to the noise. The employers are invited to verify the action effectiveness for a correct HPD use.

2.2 The European Directive for the vibration exposure and the daily exposure values (*A(8)*)

Like the noise Directive, the Directive 2002/44/EC specifies the limits and the measures for the daily operator vibration exposure.

In the Directive, HAV (hand-arm vibration) and WBV (whole-body vibration) are defined. When transmitted to the human hand-arm system, HAV is the mechanical vibration that entails risks to the health and safety of workers, whereas WBV is the mechanical vibration that, when transmitted to the whole body, exposes operators to lower-back pain and spine trauma risks.

The assessment of the level of exposure to hand-arm vibration is based on the calculation of the daily exposure *A(8)* normalised to an eight-hour reference period and based on the vibration total value a_{hv} (m/s^2), calculated as the square root of the sum of the squares (r.m.s.) of the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} measured along the orthogonal axes *x*, *y* and *z* as defined in the ISO standard 5349-1:2001 (Equation (3)).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \tag{3}$$

The *A(8)* calculation follows, considering the total exposure duration *T* (in hour, Equation (4)).

$$A(8) = a_{hv}\sqrt{\frac{T}{8}} \tag{4}$$

If many machines which transmit vibration to the hand-arm system are used during the day (each of them with its time exposure), the Equation (4) is replaced by Equation (5).

$$A(8) = \sqrt{\frac{1}{8}\sum_{i=1}^{N} a_{hv,i}^2 T_i} \tag{5}$$

where:

$a_{hv,i}$: vibration total value measured at the operator's hand-arm using the machine *i* , m/s^2

T_i: operator's exposure time when he uses the machine *i*, hour

N: number of the hand-arm vibrating machines used daily by the operator.

For the WBV, the assessment of the level of exposure to vibration is likewise based on the daily exposure *A(8)*, calculated over an eight-hour period and using the vibration total value a_v (m/s^2) through the accelerations measured along the three orthogonal axes (a_{wx}, a_{wy}, and a_{wz}) accordingly to the ISO standard 2631-1:1997. The a_v is calculated as specified by ISO 2631-1:1997/Amd 1:2010, (Equation (6)).

$$a_v = (k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2)^{1/2} \quad (6)$$

Dealing with effects of vibration on health, the multiplying factors $k_{x,}$ and k_y have a value of 1.4, while k_z factor has a value of 1, as specified in ISO 2631-1.

Also for WBV the *A(8)* uses the total exposure duration T (in hour, Equation (7)).

$$A(8) = a_v \sqrt{\frac{T}{8}} \quad (7)$$

If an operator is exposed to vibration from more than one source exposures, *A(8)* must be calculated for each separate axis using Equation (8).

$$A_l(8) = k_l \sqrt{\frac{1}{8}\sum_{i=1}^{N} a_{vl,i}^2 T_i} \quad (8)$$

where:

a_{vli} is the frequency-weighted r.m.s. value of the acceleration, determined over the time period *Ti*

$l = x, y, z$

$k_x = k_y$ =1.4 for the *x* and *y* directions; k_z = 1 for the *z* direction

The assessment of the vibration has to be made with respect to the highest frequency-weighted acceleration determined in any axis on the machine seat.

Likewise the 2003/10/EC Directive, also the 2002/44/EC Directive sets exposure action and limit exposure values (Table 2).

Table 2 Vibration exposure action and limit values (2002/44/EC Directive)

HAV *A(8)*, m/s^2	WBV *A(8)* , m/s^2	Action
A(8)=2.5	*A(8)*=0.5	Exposure action value: specific actions must be taken to safeguard exposed subjects (machine replacement/improvement, different work organisation, maintenance, health surveillance, rests, workers information, training)
A(8)=5	*A(8)*=1.15	Exposure limit value: it represents an exposure value which cannot be exceeded, because a non-acceptable risk for the exposed subject follows. The employer must take immediate action to reduce exposure below the exposure limit value

If exposed workers to HAV and/or to WBV have been observed during the phase of risk assessment, the employer must therefore acquire:

- the acceleration value (m/s^2) corresponding to the human contact point (a_{hv} for the hand-arm system, a_v for the whole body) for the machine used in the real work condition;
- the real time *T* (hour) of operator's contact with the vibrating surface.

2.3 The SNR method for the noise reduction using the hearing protector devices (HPDs)

The efficacy of the HPDs is a primary element to protect the operators from the noise, whenever it is not possible to reduce the risk at the source.

The EN ISO 4869-2 standard provides three different methods to determine hearing protector attenuation: this standard permits to evaluate the acoustic levels (A-weighted) of the exposed workers to noise sources when hearing protectors are worn.

All the three methods consider the attenuation values of the HPDs.

These methods are:

- the Octave Band Method (OBM), based on the octave band values;
- the High Medium Low frequency method (HML), which considers the A and C weighted values;
- the Single Number Rating method (SNR), which uses only the C weighted level.

The SNR (Single Number Rating) is the simplest and the most spread method. It is used to estimate the noise level under the hearing protector for a specific protection performance level (L'_{Aeq}) that given a specific C-weighted noise level (L_C). The effective A-weighted sound pressure level, L'_{Aeq}, under a hearing protector is calculated by subtracting the SNR from the C-weighted sound pressure level of a specific noise (Equation (9)).

$$L'_{Aeq} = L_C - SNR \quad (9)$$

where:

L_C is the C weighted sound level

SNR is the maximum A weighted exposure level at PPE worn for the 84% of the people.

2.4 The examined yards

In this work a public communal yard and a private yard located in the North of Italy were considered, to compare the operators' exposure to noise and vibration during the grass cut operations.

2.4.1 The public yard

The public yard belongs to a municipal service for the urban landscape management and the operators work 7.5 hours/day for 4 days, while on Friday they work 6 hours (36 hours/week).

For the grass cut tasks, four operators were identified and each of them used one machine/day. The exposure times were obtained from the job description of each worker and the values were confirmed by the yard responsible. The four operators were all right-handed, skilled and able to properly operate the machines that they used. Operators' anthropometric data are collected in Table 3.

Table 3 Operators characteristics in the public yard

Operator code	Height, cm	Mass, kg
1	183	81
2	178	80
3	180	78
4	185	84

2.4.2 The private yard

The employee of a private landscape yard in a big city in the North of Italy was interviewed. In this yard two operators were dedicated to the grass cut operation, each using many different machines during the working day (mower, trimmer, blower and so on). The noise and vibration exposure of these two operators were considered. Whereas in this private yard it was easy to measure the acoustic and vibrational levels, it was difficult to acquire the exposure times, because in these yards it is hard to have a precise job description for each worker and the tasks are distributed from time to time, according to the specific requirements. For this reason, in-field time acquisitions were necessary. Also in this case the two operators were right-handed and both of them were able to properly use all the machines. Operators' anthropometric data are collected in Table 4.

Table 4 Operators characteristics in the private yard

Operator code	Height, cm	Mass, kg
5	173	78
6	182	83

2.5 Machines characteristics

The characteristics of the machines used in the public and the private yard are reported in Table 5.

Table 5 Characteristics of the examined machines in the two yards (public and private)

Machine/tool	Type	Power, kW	Displacement, cm^3	Mass, kg	Engine speed, r/min idling - working
Public yard					
Lawn tractor	Kubota G23	17.1	898	535	900 - 3200
Brushcutter	Stihl FS 200	1.6	36.3	6.3	2800 - 9960
Mower	Yanmar YL 630	4.1	182	48	2100 - 3900
Blower	Echo PB 650	1.9	63.3	10.44	2400 - 6800
Car for transfer	Iveco Daily 35C13	92.0	2800	2340	900 - 3600
Private yard					
Lawn tractor	Ferrari 2T	32.8	1498	800	1800 - 3000
Brushcutter	Echo SRM 5000	1.8	51.7	8.1	2500 - 9800
Mower	Honda HRH 536	3.5	163	60.2	2400 - 3800
Blower	Shindaiwa EB 8520	3.2	79.7	11.5	1900 - 3850
Car for transfer	Fiat Ducato	88.0	2300	2130	900 - 3600

2.6 HPD characteristics

Operators used HPDs in both public and private yards (Table 6).

Table 6 Characteristic of the HPD used in the public and private yards

Ear protector	Type	SNR
Public yard		
Hearmuff	Peltor H9A	26
Private yard		
Banded earing	3M EAR Caps	23

2.7 Instruments

2.7.1 Noise

The acoustic measurements were carried out during the month of May 2015 accordingly to the requirements of the ISO 11204:2010, using two integrating sound level meters: a Larson Davis 824 and a Larson Davis 831. The entire measurement chain (microphone preamplifier-analyzer) is a Class 1 in accordance with the requirements of standard IEC 61672-1. The instrument was calibrated using the reference source BRÜEL & KJÆR mod. 4230, before and after the measuring cycle. The measuring chain of the LD 824 and the calibrator B&K 4230 used for the calibration of the chain were checked at the Calibration Centre LAT No. 163 on 2015/04/27. The LD 831 was verified at the Calibration Centre LAT No. 062 on 2014/04/09.

2.7.2 Vibration

WBV accelerations were measured in the same month of May 2015 along the three mutually perpendicular directions (X, longitudinal; Y transverse; Z, vertical) on the surface of the operator's seat (Figure 1), accordingly to the ISO 2631-1. A semi-rigid disc, incorporating three mutually-perpendicular piezoelectric accelerometers (ICP®, Integrate Current Preamplifier, from PCB, type 356B41 with sensitivity of 100 mV/*g*, frequency range ±5% from 0.5 to 1000 Hz), was positioned on the seat cushion of the driver.

Figure 1 Semi rigid disk positioned on the surface of the operator seat for the WBV acquisition

HAV accelerations were measured accordingly to the EN ISO 20643: 2008 standard: one or two (in function of the machine type) tri-axial accelerometers ICP by PCB (SEN020 model, 1 mV/g sensitivity, 10 g mass). All the measurement chains were calibrated with the reference source B&K 4294 calibrator before and after the measuring cycle. For the vibration measurements a LD HVM100, connected to the accelerometers, was used. The entire measurement chain and the calibrator was verified at the Calibration Centre LAT No. 002 on 2014/11/22.

Figure 2 Accelerometers fastened to the handlebar of the mower for vibration data acquisition

2.8 Measurement methodology

2.8.1 Job description

The job description and the machines used by each operator were firstly analysed. The exposure times were then acquired (Table 7), using interviews to the employers, the job planning of the operators (when available) and in-field measurements.

Table 7 Machines and corresponding exposure times (in minutes) for each operator (Op. #1 to #4 are public yard workers, while Op. #5 and #6 are private yard workers)

Machine	Op. #1	Op. #2	Op. #3	Op. #4	Op. #5	Op. #6
Car for transfers	60	60	60	60	60	60
Lawn tractor	240				120	
Mower			180		180	
Brush cutter		180				210
Blower				120		120
Pause	30	30	30	30	30	30
Manual activity	80	140	140	200	90	60
Work planning	40	40	40	40	-	-

2.8.2 In-field acquisitions

After the analysis of the works carried out by the operators in the two yards, the measurement strategy was selected based on the job to be performed. Each task was examined in order to obtain an overview and to understand all the factors which can influence the noise and vibration exposures. The measurement was planned to ensure that all significant noise and vibration events were included and the levels were representative of the noise level at the worker's ear. The noise and vibration levels for each machine were quite homogenous and for this reason the measurement duration was at least two minutes, to obtain a stabilized signal. Measurements were carried out in normal operating conditions during the work and the engine rotation speeds were monitored. The accelerometers were fixed to the handles or positioned on the seat respecting the coordinate system basicentric given by the reference standards (ISO 5349 and ISO 2631-1 respectively). Accelerations were acquired for each machine, for each hand position and for whole body and then separately analyzed.

The vibration data were processed in order to obtain the one-third octave bands and these signals were therefore weighted using the suitable weighting curves. W_h for hand arm system (as described in the ISO 5349-1 standard) and *Wk* (vertical vibration) and *Wd* (lateral and longitudinal vibration) for whole body (ISO 2631-1 standard).

Environmental conditions during the tests were appropriate for the use of the instrumentation (absence of wind and rain and temperatures ranging from 15℃ to 21℃).

Concerning noise measurements, the microphones were head-mounted at 20 cm ± 2 cm from the median plane of the operator head in line with the eyes. Possible false results produced by mechanical influence or clothing were avoided correctly fastening the microphone and the cable (ISO 9612:2011).

The assessment of the measurement results were taken considering the measurement inaccuracies determined in accordance with the metrological practice (ISO 9612:2011).

To reduce the uncertainty of hand-arm vibration measurements the tri-axial accelerometer(s) was/were oriented according to the EN ISO 20643/A1: 2012 standard and secured to the harvester handles (front and/or rear) by means of metal supports wrapped with metallic screw clamps (Figure 2).

To avoid self generated vibrations in WBV measurements, a specific care was used to inform operators how to sit down and how to move on the seat during both the seat access and the machine forward: in some cases, if the operator sits down very quickly or if he roughly moves on the seat the acceleration values may incorrectly increase (EN 14253:2003+A1:2007).

For the vibration, since there are no regulations regarding the measuring inaccuracies, three measurements for each vibration exposure (WBV and HAV) and for each machine were performed: for each replicate, the mean was then calculated and added twice the standard deviation as requested by EN 12096:1997.

2.9 Data analysis

The noise data and the acceleration values acquired in field were processed using the IBM SPSS Statistics 21 software package. To compare the data of the two yards a t-test of Student was used, at the confidence interval of 95%.

3 Results and discussion

3.1 Public yard

In Table 8 the equivalent levels, the measured acceleration values, the exposure times, the hand-arm and whole body *A(8)* and the $L_{EX,8h}$ for each of the four operators of the public yard are reported for their typical working day (450 minutes).

Table 8 Acoustic and vibration values obtained in the public yard for each operator

Grass cut	Operator n. 1					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfers	76.5	0.3	60	-	0.11	67.5
Lawn tractor	91.5	1.0	240	-	0.71	88.5
Pause	70	-	30	-	-	58.0
Manual activity	71	-	80	-	-	63.2
Activity manag.	72	-	40	-	-	61.2
Daily exposure					**0.72**	**88.6**

Grass cut	Operator n. 2					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfers	76.5	0.3	60	-	0.11	67.5
Brushcutter	95.7	7.5	180	4.6	-	91.4
Pause	70		30	-	-	58.0
Manual activity	71		140	-	-	63.2
Activity manag.	72		40	-	-	61.2
Daily exposure				**4.6**	**0.11**	**91.5**

Grass cut	Operator n. 3					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfers	76.5	0.3	60	-	0.11	67.5
Mower	83	6	180	3.7	-	78.7
Pause	70		30	-	-	58.0
Manual activity	71		140	-	-	63.2
Activity manag.	72		40	-	-	61.2
Daily exposure				**3.7**	**0.11**	**79.4**

Grass cut	Operator n. 4					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfers	76.5	0.3	60		0.11	67.5
Blower	96	2.6	120	1.3	-	90.0
Pause	70		30	-	-	58.0
Manual activity	71		200	-	-	63.2
Activity manag.	72		40	-	-	61.2
Daily exposure				**1.3**	**0.11**	**90.0**

Concerning the vibration, operators #2 and #3 exceed the exposure action values for the hand-arm system (4.6 and 3.7 m/s^2 respectively), while the operator #1 is over for the whole-body (0.72 m/s^2): nobody goes beyond the exposure limit values. On the contrary, the daily noise values for operator #1, #2 and #4 (88.6, 91.5 and 90 dB(A) each) are slightly higher than the exposure limit of 87 dB(A). In these cases HPDs are necessary. Table 9 shows how the HPD use preserve the operators from the noise risk.

Table 9 HPD attenuation in the public yard

SNR 26 dB(A)			
Machine	L_{Aeq}	L_{Ceq}	L'_{Aeq}
	dB(A)	dB(C)	dB(A)
Lawn tractor	91.5	100.1	74.1
Brushcutter	95.7	97.2	71.2
Mower	83	86.8	60.8
Blower	96	100.7	74.7

3.2 Private yard

As above mentioned, in the private yards each worker uses more machines. In Table 10 the equivalent levels, the measured acceleration values, the exposure times, the hand-arm and whole body *A(8)* and the $L_{EX,8h}$ for each operator are reported for a typical working day of 480 minutes in the private yards.

Table 10 Acoustic and vibration values obtained in the private yard for each operator

Grass cut	Operator n. 5					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfer	76.0	0.14	60	-	0.14	67.0
Lawn tractor	90.5	1.1	120	-	0.55	84.5
Mower	86.2	5.3	180	3.25	-	81.9
Pause	70.0		30	-	-	58.0
Manual activity	75.0		90	-	-	67.7
Daily exposure				**3.25**	**0.57**	**86.5**

Grass cut	Operator n. 6					
Machine	L_{Aeq}	a_v or a_{hv}	Exp. time	HAV *A(8)*	WBV *A(8)*	$L_{EX,8h}$
	dB(A)	m/s^2	minutes	m/s^2	m/s^2	dB(A)
Car for transfer	76.0	0.4	60	-	0.14	67.0
Brushcutter	92.2	7.2	210	4.7	-	88.6
Blower	96.4	3.4	120	1.7	-	90.4

Pause	70	-	30	-	-	58.0
Manual activity	75	-	60	-	-	66.0
Daily exposure				**5.06**	**0.14**	**92.6**

The operator #2 registers a hand-arm vibration value of 5.06 m/s^2, higher than the law limit, while the operator #1 exceeds the action values both for hand-arm and whole-body. The noise exposure of operator #2, 92.6 dB(A), is also higher than the limit required by the law. Also in this case the HPDs uses preserve operators from the noise risk (Table 11).

Table 11 HPDs attenuation in the private yard

SNR 23 dB(A)

Machine	L_{Aeq}	L_{Ceq}	L'_{Aeq}
	dB(A)	dB(C)	dB(A)
Lawn tractor	90.5	99.3	76.3
Brushcutter	92.2	93.5	70.5
Mower	86.2	94.2	71.2
Blower	96.4	98.3	75.3

3.3 Comparison between public and private yards

Comparing the operators' noise exposure in the two yards, there are not evident differences (Figure 3): the *t test* of Student confirms this assertion, with a significance of 0.64. Four operators registered $L_{EX,8h}$ values higher than the limit daily value of 87 dB(A) and five were over the action value of 85 dB(A): for this reason, except the operator #3, the other workers need both HPDs and to be trained and informed about the noise exposure risks.

Since all the L'_{Aeq} values obtained with the HPDs worn are less than 80 dB (A), therefore also the noise exposure of all the operators using the described machines are lower than the exposure action values. As a consequence, using these ear protectors, all the six workers of the two yards (public and private) are correctly protected from the noise risk. They may therefore use the machines for all the scheduled period of time, as also observed by other authors in a study concerning tractor operators (Aybek et al., 2010): in this last case personal protection devices reduced A-weighted equivalent sound pressure levels by 10-45 dB(A) when tractors were operated without cabins.

Other authors observed that farming and greening activities involving machinery used for prolonged periods present significant risks to operator's hearing health (Williams et al., 2002; McBride et al., 2003; Depczynski et al., 2005): as a consequence noise management strategies, other than the use of the HPDs, are essential in order to prevent noise injuries among operators. For example, mitigation and isolation of noise sources (when possible), hearing loss prevention education programs and a good training in HPD correct use and maintenance. The leaf blowers produced the highest acoustic pressure levels measured at the operator's ear (Table 8 and Table 9). As Pasanen et al. (2004) observed the engine power of the blowers is the main contributor to the machine noise emission: in this case a manufacture improvement to the engine may significantly lower the machine acoustic emission.

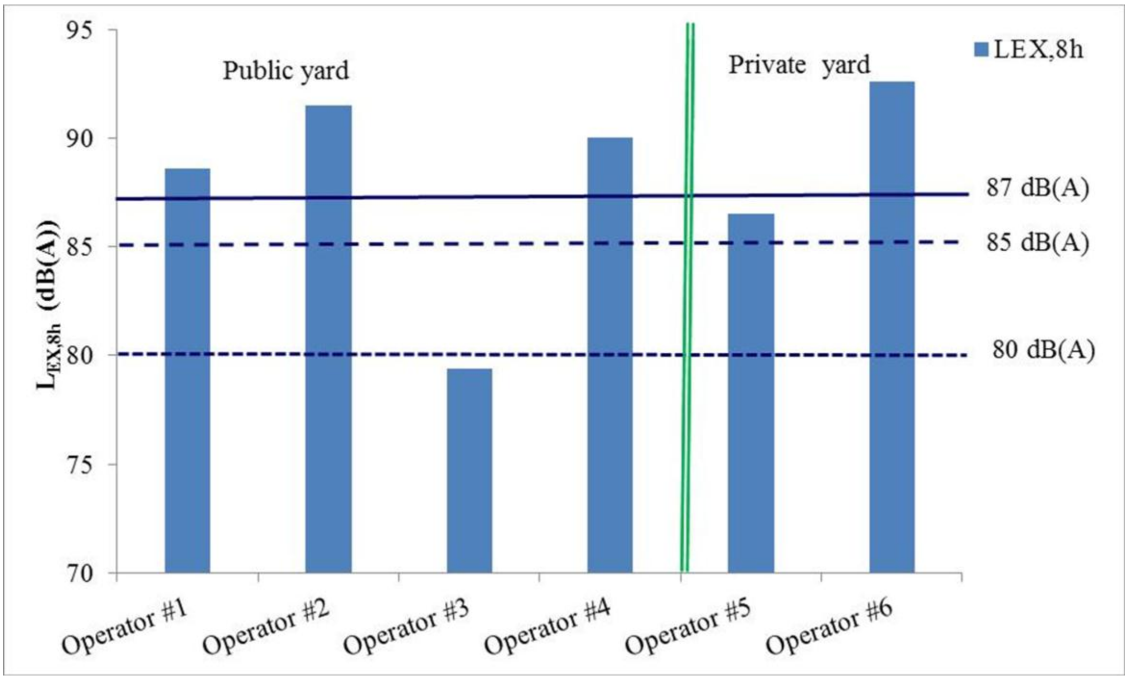

Figure 3 Daily exposure to the noise ($L_{EX,8h}$) of the 6 operators in the two yards

Figure 4 reports the vibration exposure and shows that both in public and in private yard there is one operator that exceeds the action value for the whole body and two operators that overtake the action value for the hand arm: in this last case one operator of the private yard exceeds also the limit value. For the 2002/44 Directive this last condition represents a non-acceptable risk for the exposed subject, because the prolonged use of hand held vibrating power tools can lead to the hand arm vibration syndrome that can interest the musculoskeletal, nervous and vascular peripheral structures of the upper limb, as studied by many Authors (Gemne, 1997; Bovenzi et al., 2000; Punnet and Wegman, 2004).

Specific actions must be taken to safeguard the other exposed subjects that exceed the hand-arm action limit value (anti-vibrating gloves, training, specific information and medical support) (Griffin, 2004).

Also in the case of the WBV and HAV the t-test of Student does not reveal differences among the two yards, both for hand-arm (sig. = 0.53) and whole-body (sig. = 0.76).

The operator who works in the public yard and that exceeds the action value for the whole-body uses the lawn tractor for 240 minutes: in this case an immediate possible intervention for this operator could be to limit the machine use at 120 minutes, which permits to lower his daily exposure value to 0.5 m/s^2 (value acceptable by the Directive). Unfortunately, as observed by many authors (Lines et al., 1995; Scarlett et al., 2007; Maytona et al., 2008), the WBV evaluation in this context is very complex, because it depends on many changing factors during the field work.

For example, it is strictly connected to the surface type and condition, other than the machine configuration, the performed task and the operator behaviour. The high number of combination produced by the surface, the machine configuration, the forward speed and the operator behaviour cause high ranges of unpredictable accelerations which cannot be a priori standardized. The consequence is the possibility to manifest low back disorders after some years of work, as observed by some authors since the sixties (Rossegger and Rossegger, 1960; Bovenzi, 1994).

Moreover, also the operator who performs the same grass cut operation with a different model of lawn tractor exceeds the action value working only for 120 minutes: could be that the slightly higher acceleration value measured on the seat in this context (1.1 m/s^2 against the 1.0 measured in the public yard) depended on the grass surface or other environmental characteristics. The result is that in this case, with 120 minutes of work, the action limit is surpassed: as Scarlett et al. (2005) observed, it is necessary to operate to minimise vibration exposure once levels exceed the exposure limit.

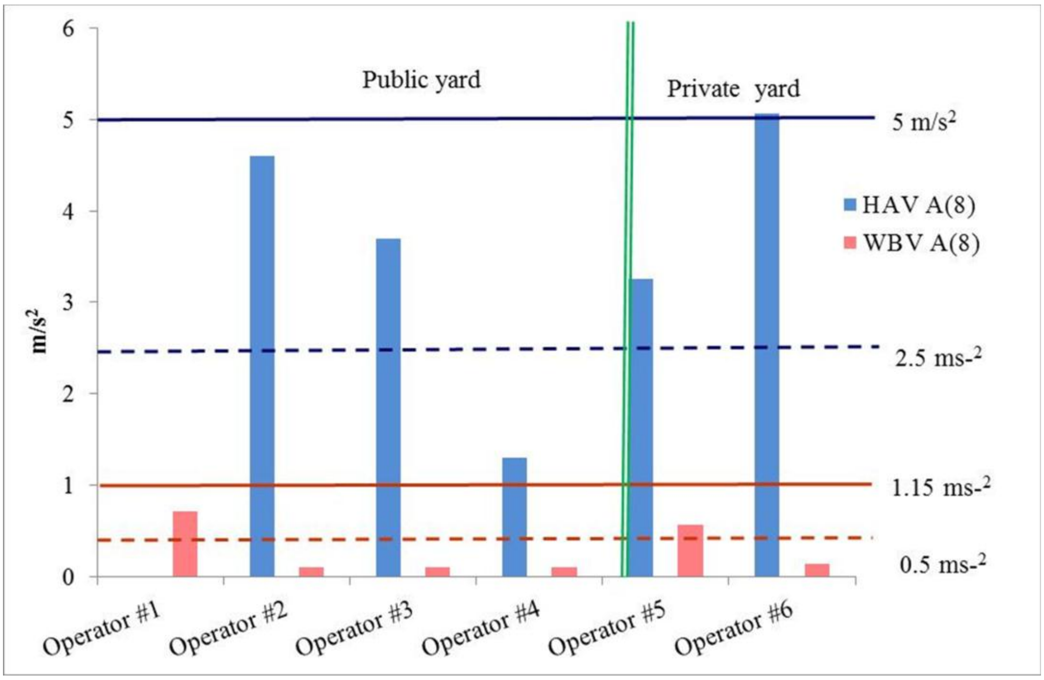

Figure 4 Daily exposure to hand-arm (HAV *A(8)*, blue) and whole-body (WBV *A(8)*, red) vibration

4 Conclusions

In this study it was observed that, independently from the yard management (public or private), almost all the operators are exposed to acoustic values higher than the limit requested by the European law. In the case of the public yard, three of the four operators are exposed to values higher than the limit value also if each of them uses one machine only: since the equivalent values of the other activities (manual activity, car for transfer and so on) are very low, the lawn tractor, the brush cutter, the mower and the blower are responsible of the noise limit value overflow. In this kind of yard it is quite impossible to operate reducing the time exposure, because each operator is dedicated to the use of one machine only and they cannot perform their tasks in a different way. The situation is not very different in the private yard, to demonstrate that it is always necessary to correctly protect the operators with HPDs (other than to train them and to submit them to periodic medical visits), because it is not possible to lower the noise problem at the source and to reduce the time exposures.

Concerning the HAV exposure, in the private yard the operators are mostly exposed because the work organization imposes them to use more vibrating tools and in total 2/3 of the employees exceed the daily action value.

In summary the operators' exposure to noise and vibration in two different green maintenance yards (public and private) show data which often are over both the limit value (noise) and the action value (HAV and WBV), also in the case of activity turnover and exposure time decrement.

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